ENGINE TEMPERATURE CONTROL APPARATUS AND METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of U.S. Provisional Application No. 60/413,489, filed September 25, 2002, which is incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

The present invention relates generally to control of cooling systems for fluid-cooled engines, and more particularly to a control system for engine cooling that uses an active water pump responsive to selected inputs to augment a mechanical water pump cooling system.

BACKGROUND OF THE INVENTION

The amount of power dissipated in the cooling system as waste heat in the internal combustion engine is approximately equal to the power being delivered to the drive train. The conventional cooling system for dissipating this heat to the atmospheric environment uses forced water circulation via a mechanical water pump to circulate cooling water to the radiator with forced air convection at the radiator via the use of a mechanical or electrical fan.

The mechanical water pump is driven by the engine, usually via belt(s). The fan is also often driven directly by the engine, usually via belt(s), and may or may not have some clutching mechanism e.g., viscosity coupling or electro-magnetic coupling. In addition, some systems employ an electric auxiliary fan in addition to a mechanically driven fan, and yet other systems may employ only electric fans.

The design of the conventional engine cooling is centered on satisfying the steady state requirements of idling and also of driving at high speeds. The mechanical water pump impeller/housing design must satisfy the circulation requirements for heat dissipation in the idle condition without too large a power penalty or drain at high speeds, where the pump impeller is turned at 7 or 8 times the idle speed.

The actual driving conditions in a passenger car are far from these steady state cases. The constantly changing load and dynamics of engine power output caused by the driver's use of the accelerator cause the power output to be constantly changing. The

most difficult scenario for the conventional cooling system to manage is that what can be termed "heat soak conditions", where the engine speed is suddenly reduced and the heat within the engine rapidly builds up in the cylinder head. As an example, consider the vehicle traveling at high speed on the freeway on a hot day, then quickly brought to an almost idle condition due to traffic gridlock. The cooling dynamics have suddenly been changed dramatically. As the rotational speed of the engine has been reduced to an idle, so has the impeller speed of the mechanical water pump. However, due to the heat content in the mass of the block and the valves in the cylinder head; the thermal conductivities of the different materials and the thermal interfaces between these components, a large amount of heat still remains in the block at the time of the rapid deceleration of the vehicle. This excess heat is rapidly transferred primarily by conduction through the head gasket to the cylinder head. This occurs while the mechanical water pump is at its lowest output. This reduction in coolant flow causes reduction in the heat transfer to the radiator. The heat content in the block and other engine components, combined with the reduction of the pumping of the heat to the radiator causes a rapid rise in temperature at the cylinder head and can begin to cause pre-ignition in the cylinders, which in turn further aggravates the problem of excess heat with inefficient combustion. This is especially notable in carbureted engines without ignition-retard feedback control.

The second scenario of heat soak is when the motor is shut off. Even though the engine is no longer doing any work, the problem with the heat in the massive block ending up in the cylinder head is very much the same as in the scenario cited above. Even though there is no danger to the moving parts of the cylinder head & valve train, there is a problem with the thermal expansion of the aluminum head on the iron block due to the temperature rise, which is fairly quick; perhaps 25 to 40 deg F in approximately 1 to 2 minutes.

Recently, attempts have been made to improve the performance of the cooling system of fluid-cooled engines by replacing the mechanical water pump with an electrically driven water pump. These electrically driven pumps generally vary the flow of coolant through the pump and radiator in response to the temperature of the cooling fluid. While electrically driven water pumps are known to mitigate the problem of heat

soak, they are known to be less reliable than mechanical water pumps. The consequences of electric water pump failure when the pump functions as the primary coolant pump can be quite catastrophic. If the pumping stops while the engine is running, the very large amount of waste heat in the engine will cause catastrophic overheating in less than a few minutes at most. Additionally, unlike the common failure modes for a mechanical system, a gradually leaking shaft seal causing a gradual loss of coolant or failure of the drive belt, failure of an electric water pump typically provides no warning. Accordingly, a need exists to provide an engine cooling system capable of maintaining engine temperature during deceleration as well as avoiding heat soak on engine shutoff, while avoiding the problem of unreliability inherent in current electrically driven water pump configurations.

SUMMARY OF THE INVENTION

The present invention is directed to an active water pump system for control of engine temperature. The active water pump is an electric pump combined with control electronics. As used herein, the term "active water pump" means an engine cooling fluid pump whose source of power and control is not directly driven by the engine in combination with its control electronics. The active water pump is used as an auxiliary cooling system to a mechanical water pump system for overall cooling control. In the cooling system of the invention, under most driving conditions, mechanical water pump provides the coolant circulation. The active water pump is active primarily during deceleration and after the engine is shut down.

BRIEF DESCRIPTION OF THE DRAWINGS

Other aspects and advantages of the invention will become apparent upon reading the following detailed description and upon reference to the drawings in which:

Figure 1 shows a prior art mechanical cooling system;

Figure 2 shows a cooling system of the invention;

Figure 3 is a block diagram of an embodiment of the invention;

Figure 4 is a flow chart of the control logic of the microprocessor of the invention;

Figure 5 is a flow chart showing the control logic of the invention;

Figure 6 is a qualitative graph of active water pump drive level vs. engine speed in rpm;

Figure 7 is a qualitative graph of active water pump drive level vs. temperature in degrees Fahrenheit;

DETAILED DESCRIPTION

The present invention is directed to an active water pump and its use to greatly mitigate the heat soak problem while driving, and virtually eliminate the heat soak problem immediately after the motor is shut off. While the invention is illustrated with respect to automobile engines, it is believed to have wider applicability to fluid-cooled engines of various types in which heat soak is known to occur.

The active water pump is an electric pump controlled by a microprocessor. The active water pump is used as an auxiliary cooling system to a mechanical water pump system for overall cooling control. Under most driving conditions, a mechanical water pump provides the coolant circulation. The active water pump is active primarily during deceleration and after the engine is shut down.

Figure 1 shows a prior art mechanical water pump cooling system. During operation of the engine, heat generated by the engine circulates through the engine block **11** to the cylinder head **12**. Engine cooling fluid circulates in an essentially closed loop through the engine block, cylinder head, and radiator via radiator hoses. A mechanical water pump **13** and a mechanical fan **14** are driven by a belt (not shown), which is connected to the engine crankshaft. The mechanical water pump propels cooling fluid through the engine block and cylinder head to the radiator. The mechanical fan moves air past the radiator to assist heat exchange between the cooling fluid in the radiator and the outside air. Because belts attached to the engine crankshaft drive both the fan and the mechanical water pump, the output of the pump and the speed of the fan are directly proportional to the engine speed in RPM. The mechanical water pump **13** pumps cooling fluid through channels in the engine block **11** and cylinder head **12** where the fluid adsorbs heat from engine operation. The heated fluid then flows through the effluent engine cooling water hose **15** to the radiator tank input **16.** At the radiator **17**, air flowing through the radiator cools the fluid. An auxiliary fan **18** may be provided to provide

airflow through the radiator when the engine is shut off. After passing through the radiator, the cooling fluid then is pumped by the mechanical water pump **13** through the radiator tank output **19** and the input cooling water hose **20** and back through the engine. A thermostat **21** controls a valve to divert some of the cooling fluid around the radiator when the engine block temperature is below a set point.

The mechanical water pump system operates well at constant engine speed. When, however, the engine decelerates, the mechanical pump slows. Although under deceleration there is decreased heat generation due to engine load, the heat flux into the coolant continues because there is heat stored in the engine, especially in the massive block. Because the pumping rate of the conventional cooling system depends upon engine speed, on deceleration the mechanical pump is unable to direct a sufficient flow of fluid to the radiator, and a condition known as heat soak occurs. The heat flux from the engine to the coolant is greater than the heat flux from the radiator to the environment, causing a rise in the engine coolant temperature. Controlled combustion in the cylinders is quite sensitive to the temperature in the cylinder head. It is accordingly desirable to be able to keep the temperature in the cylinder head as constant as possible during operation. This also helps to minimize thermally induced mechanical stresses at the interface of the aluminum head and the iron block or cylinder case in the conventional internal combustion engine.

Figure 2 shows the engine cooling system of the invention. Parts corresponding to those in the prior art cooling system have the same numbers as in Figure 1. In addition to the mechanical water pump **13** the cooling system of the invention includes an electrically driven water pump **22** which receives cooling fluid from the radiator tank output **19** through an electrically driven water pump input hose **23.** In the preferred embodiment, the pump pumps cooling fluid through the electrically driven water pump output hose **24** into the cooling channels of the cylinder head **12**. The output cooling fluid could, however, be routed through the engine block and then into the cylinder head.

The electric water pump controller **25** controls the electrically driven water pump **22.** The controller contains a logical circuit that receives inputs from sensors that sense engine temperature, engine speed or throttle position, the on/off state of the ignition switch, and optionally, vehicle speed. The controller's output signals are switching

signals to the fan relay **26** for the auxiliary fan **18** and to the electrically driven water pump **22**.

The controller for the active water pump determines the drive level of the active water pump in response to the temperature of the engine or the coolant; the engine speed or frequency; the ON/OFF state of the engine ignition system, and optionally, the speed of the vehicle. The controller used with an active water pump will not only greatly mitigate heat soak conditions while driving, but will also virtually eliminate post-shutoff heat soak. The controller may drive an electric auxiliary fan in addition to the active water pump and control the fan in a similar manner as the active water pump in that the same detected states of the variables Temperature; Engine Speed; Ignition State and Vehicle Speed will determine the response of the fan drive level. The use of an electric auxiliary fan is a desirable but not essential component. It is desirable to use it in eliminating the post-shutoff heat soak, but is not essential to the primary controller function of mitigating heat soak while driving by powering the active water pump in a manner which is complementary to the mechanical water pump so as to better maintain the pumping of heat to the radiator, irrespective of engine speed and thereby enhance the dissipation of waste heat to the atmospheric environment.

The principle action of the active water pump controller is to drive the active water pump in a manner to complement the mechanical water pump by pumping water when the mechanical pump output is low and the sensed state of temperature is above a set point. In particular, the active water pump controller maximizes the drive level when the temperature is hot and the engine speed is low. The precise algorithm for this control can be optimized or refined in practice, but the intent and qualitative function is clear. The controller driving an active (electrically driven) pump in the aforementioned manner greatly enhances the heat dissipation at the radiator in the times when the engine speed is low and the temperature requires it. This enhancement of cooling is very effective at mitigating the heat soak phenomenon in stop & go city driving in high traffic scenarios where there are repeated short accelerations followed by braking. In these conditions, the heat soak in the cylinder head often becomes high enough to cause pre-ignition (pinging) most notable at the initial acceleration after a decrease in vehicle speed. These inefficient combustions have a much higher heat to work ratio and cause an even greater rise in

cylinder head temperature and cause much higher hydrocarbon emissions as well. Carbureted engines are most prone to this problem. The active water pump controller in conjunction with an active pump can lower the peak temperatures in the cylinder head in this type of scenario by as much as 25 deg F.

The active water pump controller & active pump is also effective is in preventing virtually all heat soak after the combustion in the engine is shut off. If the active pump is run with an auxiliary electric fan for only 1 to 2 minutes, the peak temperature reached in the cylinder head can be reduced by 30 to 40 deg F. Heat soak temperatures in the cylinder head often reach 220 to 230 deg F. Running the active water pump and auxiliary fan just 1 to 2 minutes virtually eliminates this heat soak by preventing almost all temperature rise after shutoff. This better maintenance of temperature stability, especially preventing excessive temperatures not only improves combustion, but will also enhances the longevity of the head gasket seal between cylinder head and block.

Figure 3 shows a block diagram of the control circuit of the invention. At the heart of the active water pump of the invention is a microcontroller **30.** The microcontroller may be a custom-designed microprocessor, or may be a commercially available processor, such as an Atmel AVR 90S4433 processor. Inputs connected to the microcontroller **30** include a temperature sensor **31**, key ignition on/off sensor **32**, an engine speed or throttle sensor **33** and optionally, a vehicle speed sensor **34.** The temperature sensor may be a pipe plug thermister, such as an Omega Engineering THX-400-NPT series thermister. The thermister sender is placed in the cooling path, preferably in the effluent path from the cylinder head. The engine speed may be determined directly by a sensor in the spark ignition circuit, such as directly at the ignition coil or indirectly from an engine control module tachometer circuit in the more modern computer controlled vehicles. Alternatively, the engine speed could be sensed directly from the crankshaft or camshaft using a sensor like a Hall Effect Sensor and a counting or timing circuit.

The microcontroller outputs may include a PWM DC output to the electrically driven water pump **35.** A PWM output provides variable seed operation to the pump. The drive level to the pump and thus the output of the active pump runs inversely to the mechanical pump. Optionally, a second output for operation of an auxiliary fan may be

provided. This output is connected to an operational amplifier **36** such as a National semiconductor LM 759, which is in turn connected to a fan relay and then to the fan.

Figure 4 is a logical controller flowchart for an embodiment of the invention under several operational conditions. The inputs to the controller are engine temperature T, switched battery voltage Vk, and sensed engine speed S. The controller is set to a desired engine temperature Ts, and engine speed transition point Sh. Ts is set approximately to the thermostat set point temperature, and Sh is set to a value that distinguishes between freeway driving speeds and stop & go city driving. The value of Sh depends upon the particular vehicle, and may be user settable. A value of about 2200 rpm can be appropriate. There may be a potentiometer or other suitable adjustment mechanism, which may be mounted in the passenger compartment and accessible by the driver to adjust Ts and Sh. Alternatively, the adjustments may be located elsewhere and be set only on installation of the active water pump. In practice, virtually no adjustment is required beyond some initial optimization after installation. On wake up, the controller goes into its logic cycle **1** in which it determines the input values. If the engine is switched to off (Vk=0) and the engine temperature is below Ts (condition **2**), the controller enters its sleep state, where it shuts off and remains off until the ignition switch is turned on. If the ignition is switched from on to off when the engine temperature is higher than Ts (condition **3**), the controller cycles to its normal shutoff cycle. The fan relay and active water pump remain on until the engine temperature is less than Ts. The controller then shuts off and remains shut off until the ignition switch is turned on.

When the ignition switch is on, the controller monitors the engine temperature and speed. As long as the engine temperature remains below Ts, the fan relay and active water pump remain off and the controller continues to receive input from the sensors (condition **1**). If the engine temperature rises above Ts, and the engine is running at low speed (condition **4**) the controller cycles through its low speed heat soak mitigation cycle. Both the fan relay and the active water pump are on and remain on until sensors detect a different state. If the engine temperature is above Ts, and the engine speed is high, for example above 2200 rpm. The controller cycles to a sustained high speed driving cylinder head temperature gradient mitigation cycle (condition **5**). The active water pump cycles on for a time that is a determined by the temperature T, set point Ts of the

controller, and the running microcontroller clock time t, and then returns to its logic cycle 1. The active water pump may include a variable speed electrical pump, in which case, the logic may include parameters for varying the pumping rate of the pump as well as the on off cycle.

Figure 5 is an operational flow diagram of a second embodiment of the active water pump. In this embodiment, the active water pump controller includes an additional input, vehicle speed, to aid in distinguishing freeway driving from city driving. The output includes an additional high-speed mode. When the vehicle speed is above a set point, the electrical water pump is turned on for a time that is a determined by the temperature T, set point Ts of the controller, and the running microcontroller clock time t.

Figure 6 is a qualitative diagram of the duty cycle of the active water pump as a function of engine speed. At low engine speed, the active water pump provides the majority of the fluid circulation. When the engine speed increases above the speed transition point Sh, the active water pump begins to cycle on and off and the mechanical water pump provides more of the circulation. As the engine speed is increased, the mechanical water pump provides more of the fluid circulation and the percent provided by the active water pump gradually decreases. Eventually, the engine speed is sufficient (above Sh) for the mechanical water pump to maintain engine temperature and the active water pump goes into the high-speed mode. While the engine speed remains above Sh, the controller remains in the High Speed mode. In this mode the controller turns the pump on in response to both the measured temperature "T" and time "t"; periodically turning the pump on to reduce temperature gradients in the back of the cylinder head.

Figure 7 is a qualitative diagram of the duty cycle of the active water pump as a function of engine temperature. The active water pump is not turned on until the temperature reaches the set point, and provides a significant portion of the cooling when the fluid is at high temperature, regardless of engine speed or ignition on/off state.

While the foregoing disclosure contains much specificity, it should be understood that these are given by way of example only. The scope of the invention should not be limited by the specific examples given above, but only by the appended claims and their legal equivalents.